UNPUBLISHED PRELIMINARY DATA

THE ANTENNA LABORATORY

N64-15186

CODE-1

26p.

CR-55545

RESEARCH ACTIVITIES in ---

Automatic Controls · *Antennas* · *Echo Area Studies*
Microwave Circuits · *Astronautics* · *E M Field Theory*
Terrain Investigations · *Radomes* · *Systems Analysis*
Wave Propagation · *Submillimeter Applications*

OTS PRICE

XEROX $ 2.60ph.

MICROFILM $ 0.98 mf.

SEMI-ANNUAL REPORT
1 May - 31 October 1963

Theoretical and Experimental Analysis of the Electromagnetic Scattering and Radiative Properties of Terrain, with Emphasis on Lunar-Like Surfaces

Grant Number NsG-213-61

1388-12 1 November 1963

Prepared for
National Aeronautics & Space Administration
1520 H Street, N. W.
Washington, D. C., 20325

Department of ELECTRICAL ENGINEERING

THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION
Columbus, Ohio

NOTICES

(NASA CR-55545;

(REP~~ORT~~ t. 1388-12) OTS: # see cover

REPORT
by
THE OHIO STATE U~~NIVERSITY~~ RESEARCH FOUNDATION,
COLUMBUS~~, OHIO 43212~~
660 3005 Antenna Lab.

Sponsor — National Aeronautics and Space Adm.
1520 H Street, N. W.
Washington, D. C., 20325

(NASA Grant ~~Number~~ — NsG-213-61)

Investigation of — Theoretical and Experimental Analysis of the Electromagnetic Scattering and Radiative Properties of Terrain, with Emphasis on Lunar-Like Surfaces

Subject of Report — Semi-Annual Report, 1 May - 31 Oct~~ober~~. 1963

Submitted by — Antenna Laboratory
Department of Electrical Engineering

Date — 1 Nov~~ember~~. 1963 26p refs

[5]

ABSTRACT

15186

This report reviews work aimed at clarifying the relations between the electromagnetic scattering properties of a surface (in particular the lunar surface) and its surface structure, carried out under National Aeronautics and Space Administration Grant Number NsG-213-61 during 1963. Measurements of the complete bistatic scattering pattern of a number of rough surfaces were carried out at X-band. Theoretical studies have been made of the polarization transformation properties of rough surfaces, and these have been used to interpret lunar scattering measurements made with linear polarization. Other studies of the lunar scattering problem have been concerned with the relation between spectrum and angular dependence (for CW scattering experiments) and with the correlation properties of the scattered signal (for two-frequency scattering experiments). A 10 kilowatt radar at S-band, with transmitter in Athens, Ohio has been set up. This will be used with The Ohio State University Phase-Locked Array Antenna to measure several properties of the lunar scattering. Author

CONTENTS

SEMI-ANNUAL REPORT

I. INTRODUCTION

This report summarizes work carried out during the past year on studies of the relations between the scattering properties of moon-like surfaces and their surface features. The reasons for an interest in such studies, and a review of the approach taken, may be found in previous progress reports[1, 2], and will not be repeated here.

As in the past, work has been carried out in three principal areas. These are: (i)Theoretical studies of the scattering from rough surfaces; during the past several months, these have concentrated mainly on the polarization transformation properties of rough surfaces, and on the frequency dependence of the scattering. (ii) Measurements of the scattering properties of a number of moon-like rough surfaces on a laboratory scale; during the past year these have been aimed at establishing the complete bistatic scattering pattern, and the polarization behavior, of such surfaces. (iii) Measurements of the actual scattering properties of the moon; during the past year, the major part of the entire effort on the grant has been aimed at setting up a lunar radar experiment with which may be measured first the doppler spectrum, and subsequently the "adjacent frequency" correlation properties, of the lunar scattering. Each of the above topics will be discussed in greater detail below.

II. THEORETICAL STUDIES

Theoretical studies have had as their principal objective the interpretation of the results of the two measurement programs, dealing with scattering from artificial surfaces, and the lunar surface, respectively.

A. Normalization of Scattering Cross-Section Measurements

In measuring the bistatic cross-section of moon-like surfaces, it is necessary to relate the surface cross-section to the cross-section of a standard target in terms of the ratio of the power returned

by the two scatterers. To get an absolute scattering cross-section from such data, one must, in principal, solve an integral equation. To avoid this, an approximate procedure has been worked out, and a set of normalization tables has been computed on the IBM 7090. This work is described in detail in a special report[3].

B. Polarization Properties of Surfaces

One of the more sensitive, but little explored indicators of surface roughness is the polarization transforming properties of a surface. Some experimental evidence is becoming available, as a result of the measurements described in section III. In order to interpret and organize these data a study of the general theory of polarization transformation has been carried out, and will be described in a special report. Particular attention has been given, in this work, to determining under what conditions there can be simple relations between the vertical, horizontal, arbitrary linear, circular cross-polarized, etc., back-scattering cross-sections of rough surfaces. Such relations are important for interpreting lunar scattering measurements made using linear polarization. This is because the local polarization state on different parts of any particular range ring of the moon, when illuminated from the earth, will vary from vertical to horizontal and back to horizontal. As one example of these general relations, there is a class of surface for which the return from a range ring experiment would give average cross-section of

$$\sigma_{aa} = \frac{1}{8}\left[3\sigma_v + 3\sigma_h + 4\sigma_x + 2\alpha\sqrt{\sigma_v\sigma_h}\right]$$

for the case where transmitter and receiver had the same linear polarization, and of

$$\sigma_{ax} = \frac{1}{8}\left[\sigma_v + \sigma_h + 4\sigma_x - 2\alpha\sqrt{\sigma_v\sigma_h}\right]$$

for the case where the transmitter and receiver were cross-polarized. Here

σ_{aa} = (average radar cross-section/unit area) of range ring (R and T have same polarization)

σ_{ax} = (average radar cross-section/unit area) of range ring. (R and T have cross polarization)

σ_h = (average radar cross-section/unit area) R and T horizontally polarized

σ_v = (average radar cross-section/unit area) R and T vertically polarized

σ_x = (average radar cross-section/unit area) R and T cross polarized

α = factor ($0 < \alpha < 1$) depending on phase coherent properties of the surface as a scatterer.

A number of similar results, relating various measurements with linear and circular polarization to each other, and to the fundamental scattering parameters of the surface, have also been obtained.

C. Frequency Properties of Surface Scattering

The third area of theoretical studies has been concerned with the interpretation of the possible experiments that may be carried out with the lunar radar system described in Section IV. One special report[4] has been published which solves the integral equation that relates the doppler spectrum of a planetary surface to the angular dependence of the scattering cross-section (i.e., that relates the results of a CW and a short pulse measurement of the lunar scattered power). Thus a firm basis has been laid for interpreting the first set of experiments to be run with the lunar radar. Other studies, not yet completed, are concerned with the relation between the surface structure of the moon and the results of a planned "two-frequency" experiment, in which the experimental parameter is the correlation between the scattered power from the moon as measured at two nearly equal frequencies. This work is still in progress.

III. BISTATIC MEASUREMENTS

A. Bistatic Radar Measuring System

The radar system used to obtain the bistatic scattering measurements contained in this report is shown in Fig. 1. The system is a modulated CW radar and operates at 10 KMC. The transmitting and receiving antennas are circularly polarized and obtained by the use of circularly polarizing windows[5]. The antennas are 12 inch horns with dielectric lenses designed to give an optimum radiation pattern at the operating range of 13 feet. An electronic integration is used to

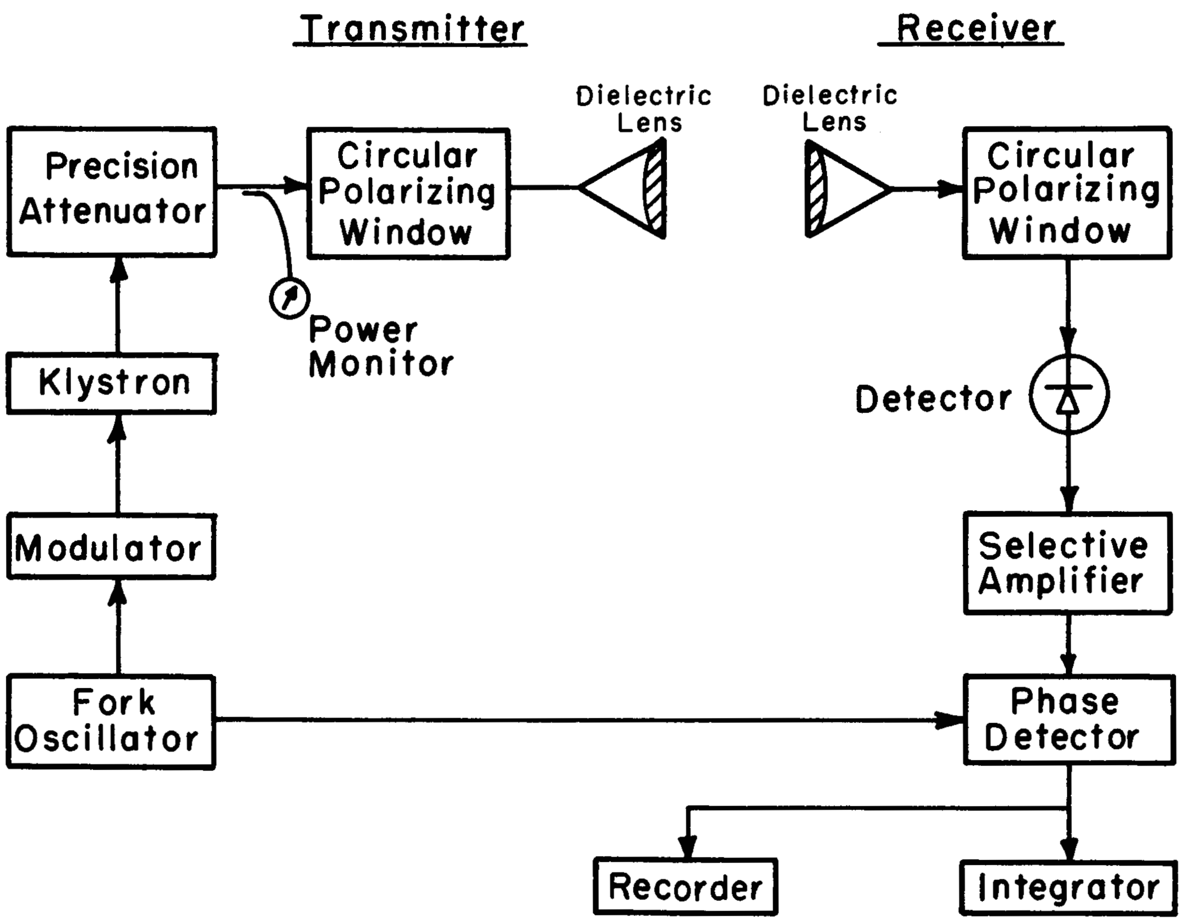

Fig. 1. Block diagram of X-band bistatic radar.

average the return from the terrain to obtain an average scattering coefficient and to increase the sensitivity of the system. The recorder is used to monitor the instantaneous value of return and to detect any unusual changes in the return from the terrain.

B. Measurement Procedure

Figure 2 shows a photograph of the complete radar system in position for a typical measurement. The major portion of the equipment with the exception of the RF section of the receiver was installed in the truck. The RF section of the transmitter including the klystron is mounted at the end of the truck boom. The receiving antenna and crystal detector are mounted on the mobile tower. The surface or material to be measured is placed in the railroad car (Fig. 2). The railroad car is moved slowly along the track and a continuous measurement of the radar scattering is made. The railroad car is of sufficient size that many independent samples of terrain can be averaged. Figures 3 and 4 show the geometry involved in obtaining the measurements.

To insure that no scattering contributions were being received from the wood bottom of the railroad car, the entire inside bottom surface of the car was covered with an absorbing material. Sand was then placed over the absorbing material (Hairflex) to a depth of 14 inches (the usual operating condition). It was found that the amplitude of the scattering from the sand was the same with the wood bottom covered or not covered with Hairflex. In order to obtain forward scattering measurements, $\phi = 0^{\circ}$, consideration must be given to the coupling between antennas. A check was made to determine the amount of transmitted power coupled directly into the receiving antenna and not being reflected by the terrain. This was accomplished by placing a screen made of Hairflex between the transmitting and receiving antennas, sufficient in height to cover the reflected signal from the surface and yet not obstructing the direct path between antennas. It was found that the coupling was insignificant. This was due to two factors: (1) the major portion of the scattering measurements were made with the transmitter left-circularly polarized and the receiver right-circularly polarized, and (2) the narrow beamwidths of the antennas. The entire system was calibrated on an absolute echo-area basis using the sphere as shown in Fig. 5.

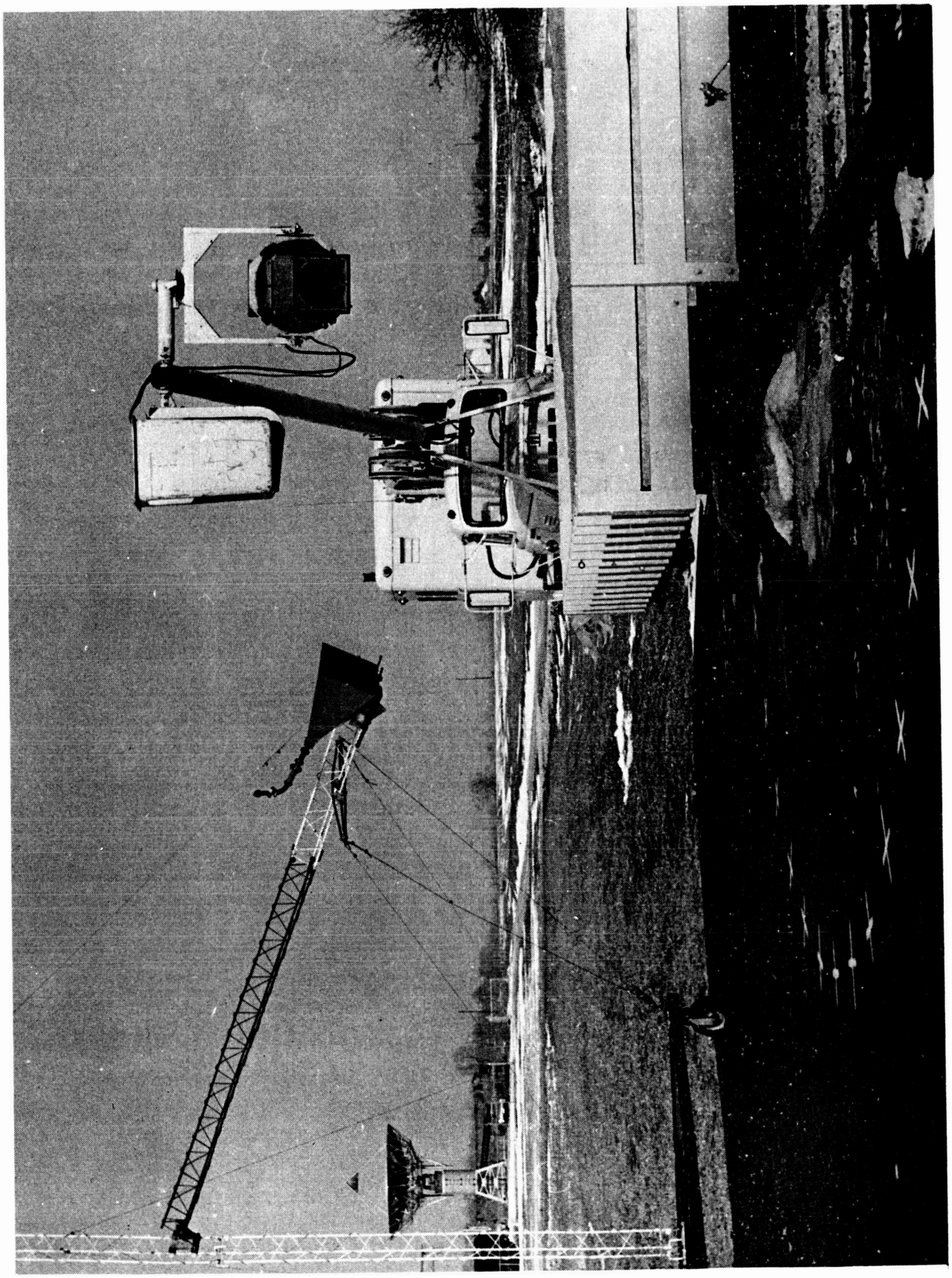

Fig. 2. Bistatic radar system.

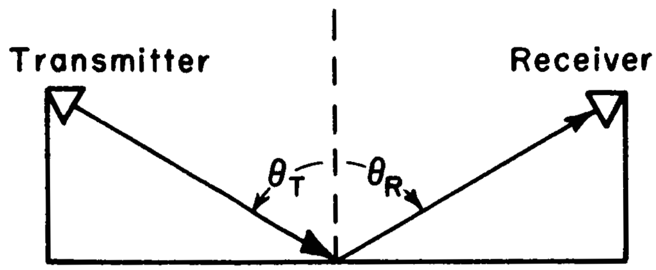

Fig. 3. Geometry showing incidence angle.

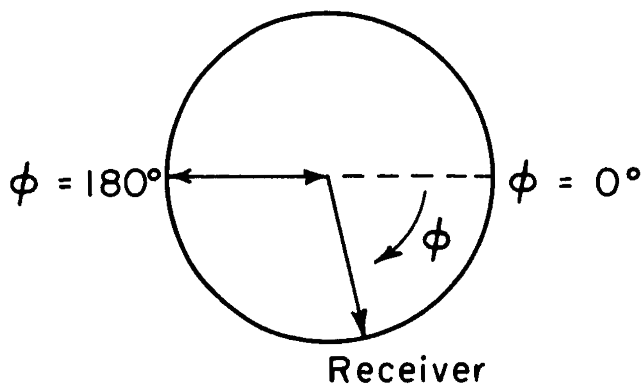

Fig. 4. Geometry showing bistatic angle.

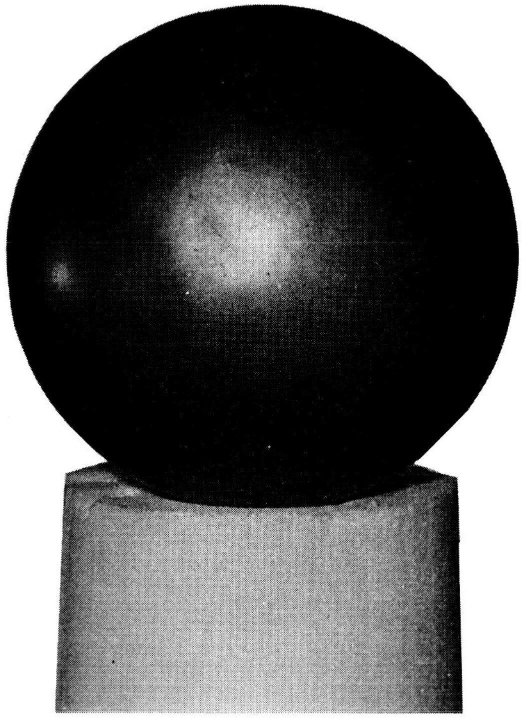

Fig. 5. Calibration standard.

C. Experimental Measurements

The results of the first phase of the bistatic scattering measurements are shown in Figs. 6 and 7. The measured values of normalized echo area (σ_o) expressed in db are shown as a function of bistatic angle (ϕ) and incidence angle (θ). The measurements were obtained using a frequency of 10 KMC, with the transmitting antenna left-circularly polarized and the receiving antenna right-circularly polarized. Figure 6 shows the bistatic scattering from smooth sand and Fig. 7 the scattering for the same sand with small changes in slope made in the surface. The sand is of the common masonry variety, with a measured dielectric constant of $\epsilon_r = 2.2$ and $\tan \delta = 0.029$. It can be seen from Figs. 6 and 7 that the magnitude of the bistatic scattering as well as the backscattering is dependent upon both the incidence angle (θ) and the surface roughness. For the case of the smooth sand, the magnitude of the forward scattering is proportional to the incidence angle. As the angle of incidence increases, more of the energy is reflected into the forward lobe ($\phi = 0^o$) and less energy is contained in the region $\phi = 20^o$ to $\phi = 180^o$. The effect of increased

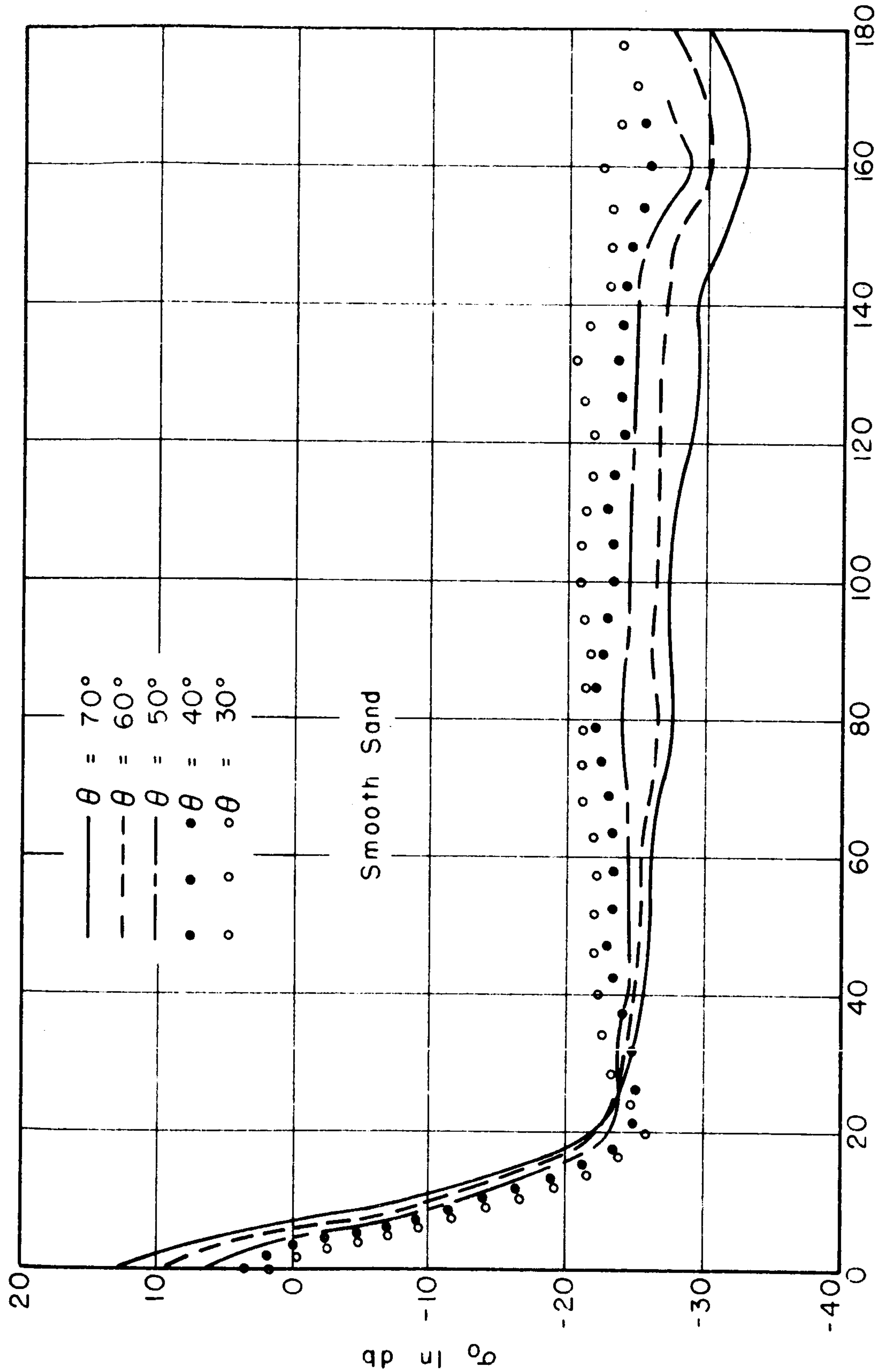

Fig. 6. Bistatic scattering from smooth sand.

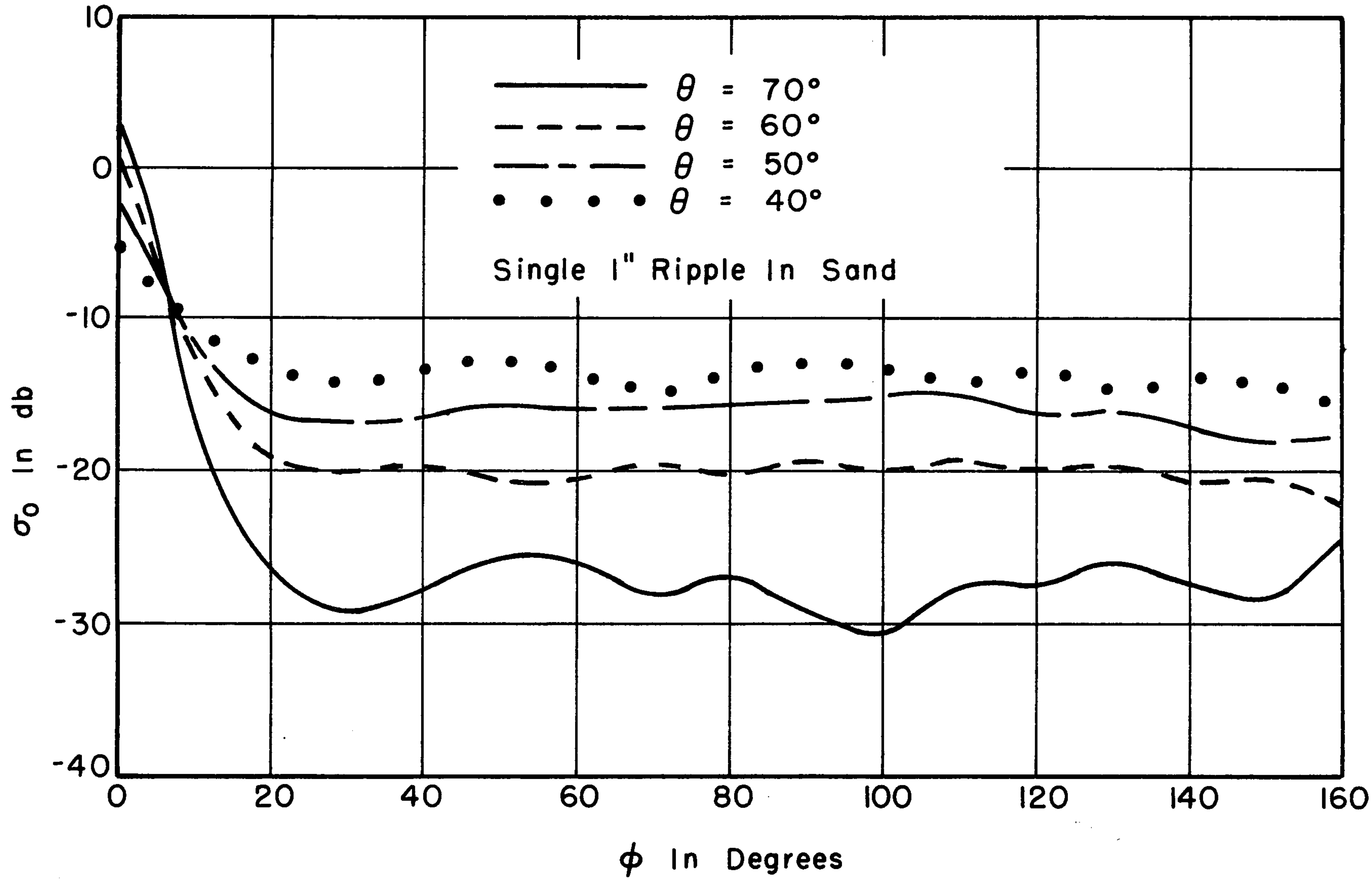

Fig. 7. Bistatic scattering from slightly rough sand.

surface roughness is quite evident in Fig. 7 where the magnitude of the forward scattering is decreased and the remaining portion of the scattering is increased. The magnitude of σ_0 for both the smooth and slightly rough sand, particularly in the backscattering region, is greater than that for the same general type of sand[6]. Preliminary dielectric constant and loss tangent measurements indicate this is due to the decreased moisture content of the sand in the railroad car as opposed to sand on the ground. The decreased moisture content would result in less incident energy being absorbed and an increase of the scattered energy. The results of the bistatic scattering measurements from the other phases of the experimental program are being processed and will be presented in a forthcoming technical report.

IV. LUNAR RADAR EXPERIMENT

The work on this phase of the grant, the measurement of the lunar scattering properties by doppler techniques utilizing The Ohio State University "Saucer Field," has been concerned with two areas of work. One is the development and construction of the transmitter facility at Ohio University in Athens, Ohio. The second phase concerns theoretical studies of the doppler mapping technique of the moon and interpretation of the forthcoming experimental data. These two phases of work are discussed separately.

A. Transmitting and Receiving Facilities

Originally it was planned to use The Ohio State University "Saucer Field" array shown in Fig. 8 as a receiver and make use of several transmitters operated by other organizations for lunar illuminations. However, this proved to be an unsatisfactory approach in regard to the lunar illumination problem. Therefore, a 10 KW CW transmitter, a 30 foot parabolic reflector and antenna mount were acquired. Figure 9 shows a sketch of the moon mapping experiment by doppler techniques. The receiving array consists of four 30-foot dishes phase-locked together at an intermediate frequency to give the capability of a 60-foot dish. The effective bandwidth of the receivers can be varied from approximately 250 cps to 14 KC. The design frequency of the array is 2270 MC.

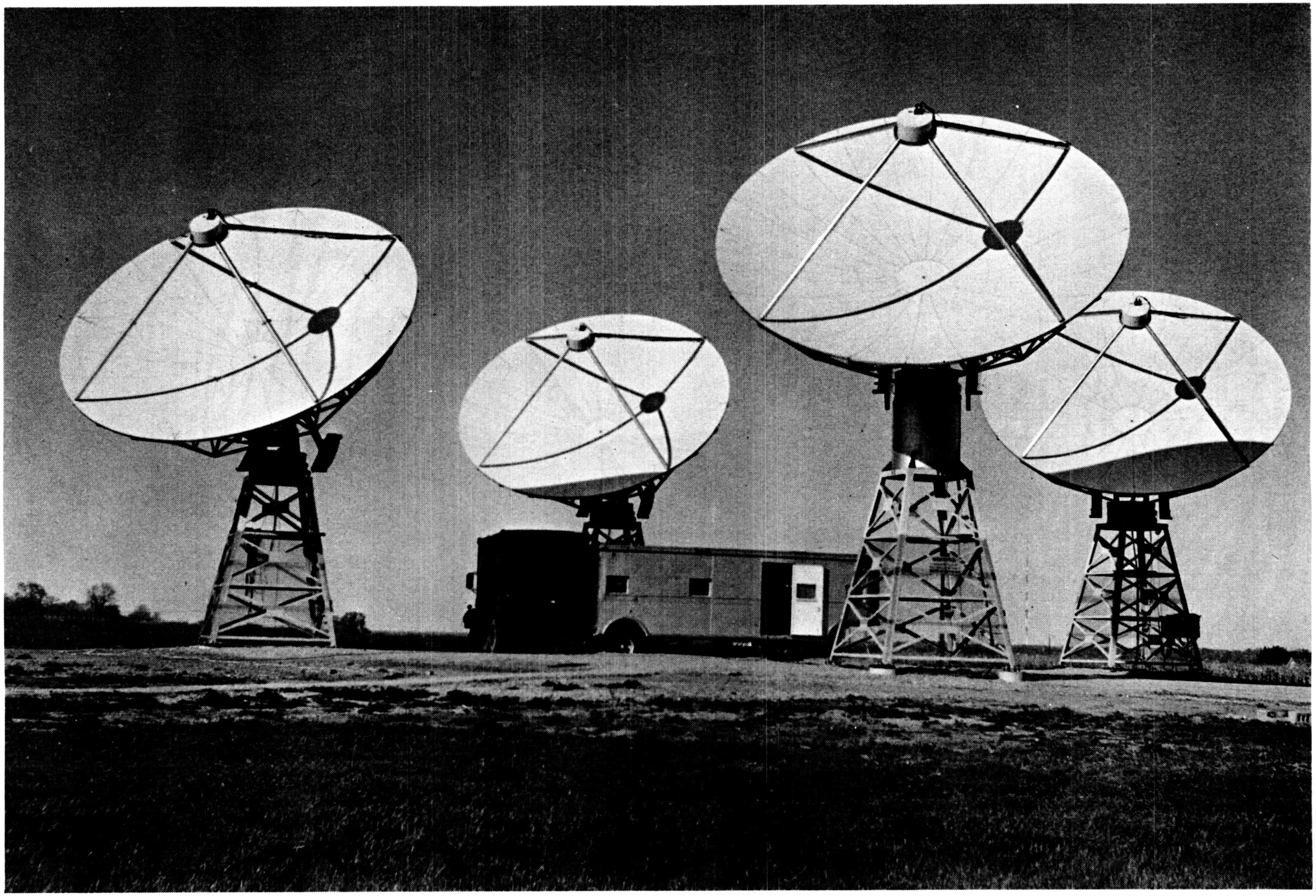

Fig. 8. The Ohio State University Phased Array Facility.

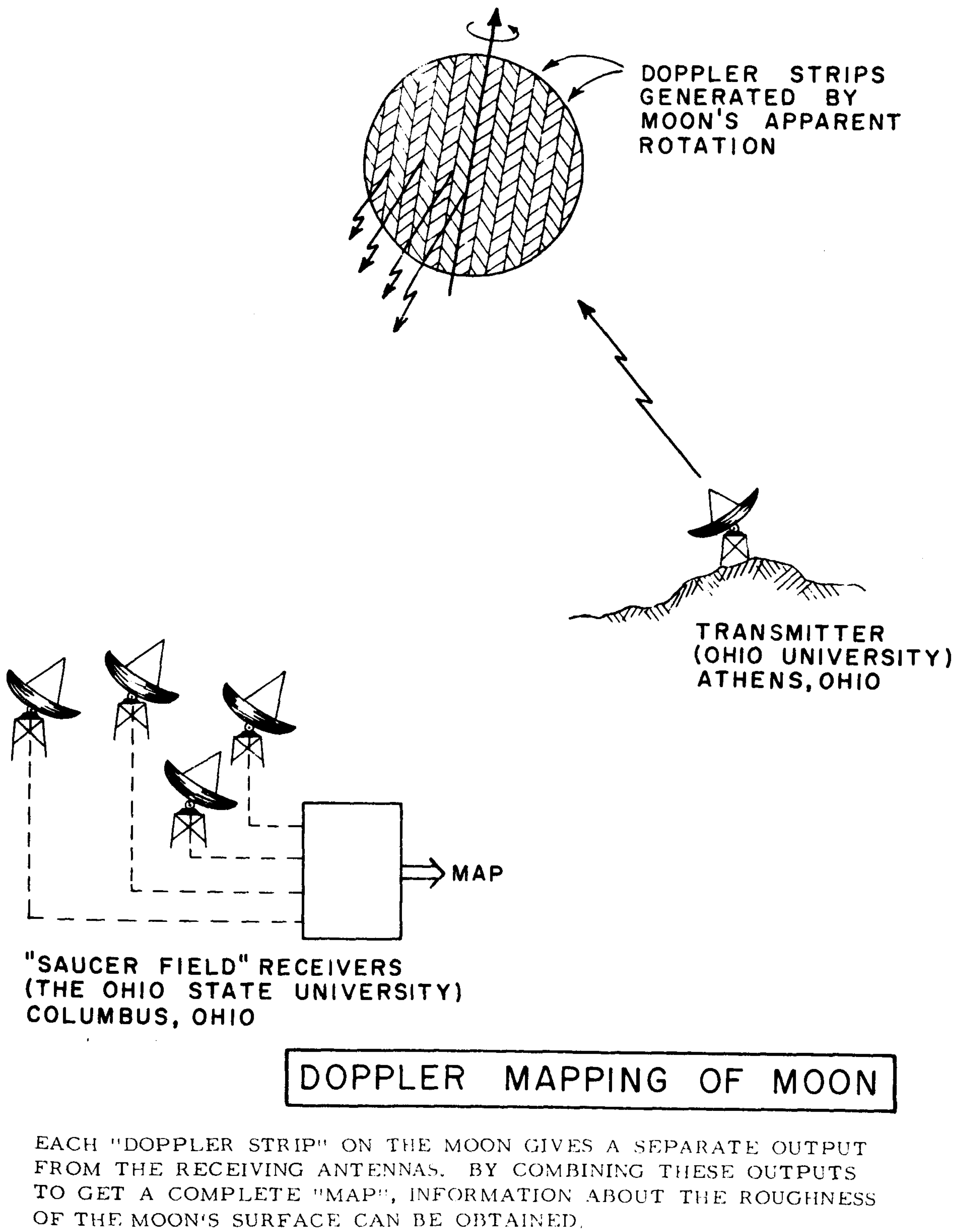

Fig. 9. Doppler mapping of the moon.

The transmitter facility consists of a 30-foot parabolic reflector and a 10 KW CW transmitter. Figure 10 shows a photograph of the parabolic reflector installed at Ohio University, Athens, Ohio. The solid surface reflector designed for S-band is usable for wavelengths up to X-band. Figure 11 shows a photograph of the 10 KW transmitter. The transmitter is capable of operating over a frequency range of 1700-2400 MC and is suitable for CW-FM operation, thus permitting range resolution without going to pulse operation.

The selection of the site at Ohio University for the transmitter was based upon such factors as transmitter-receiver isolation, radiation hazards, azimuth and elevation restrictions imposed by the terrain contour, and the general problems associated with a high-power transmitter. Preliminary measurements were made to determine the propagation loss between the transmitter and receiver sites. Figure 12 shows the results of the propagation measurements as a function of antenna height above the hill. A small parabolic reflector was used at the transmitter site and The Ohio State University phased array was used as the receiver. To take advantage of any possibility of increasing the isolation between transmitter and receiver, the transmitter antenna was lowered by removing part of the hill. The propagation loss between the transmitter and receiver should be adequate especially for the doppler mapping of the moon experiment. Due to the doppler shift generated by the moon's motion the received signal from the moon will be shifted in frequency from the transmitted signal by an amount that will usually be outside the passband of the receiver. Thus, if the receiver is tracking on the doppler frequency, any leakage signal from the transmitter will be outside the passband of the receiver, except for a short interval when the doppler shift in frequency is equal to or less than the bandwidth of the receiver. In order to achieve the frequency stability that is required for the doppler mapping of the moon, the klystron exciter is stabilized by a phase-locked oscillator stabilizer as shown in Fig. 13.

The transmitter facility is almost completed and should be in operation within a few weeks.

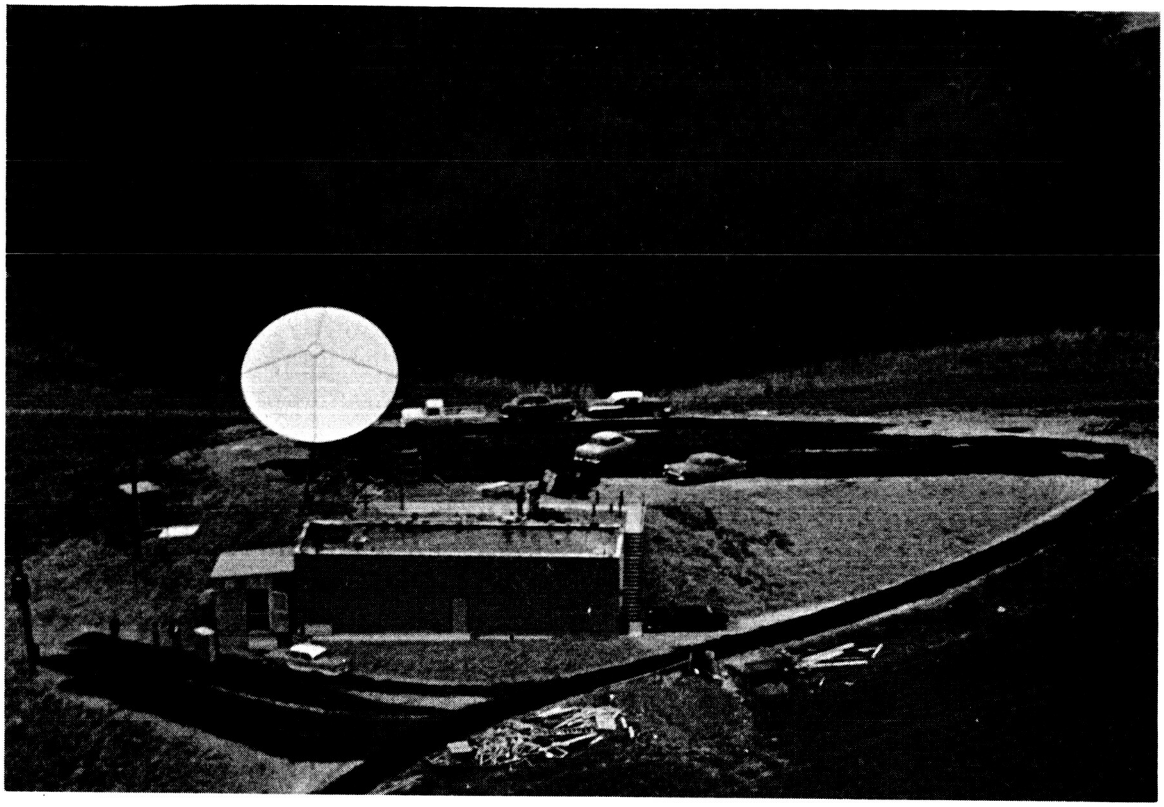

Fig. 10. 30-foot transmitting antenna.

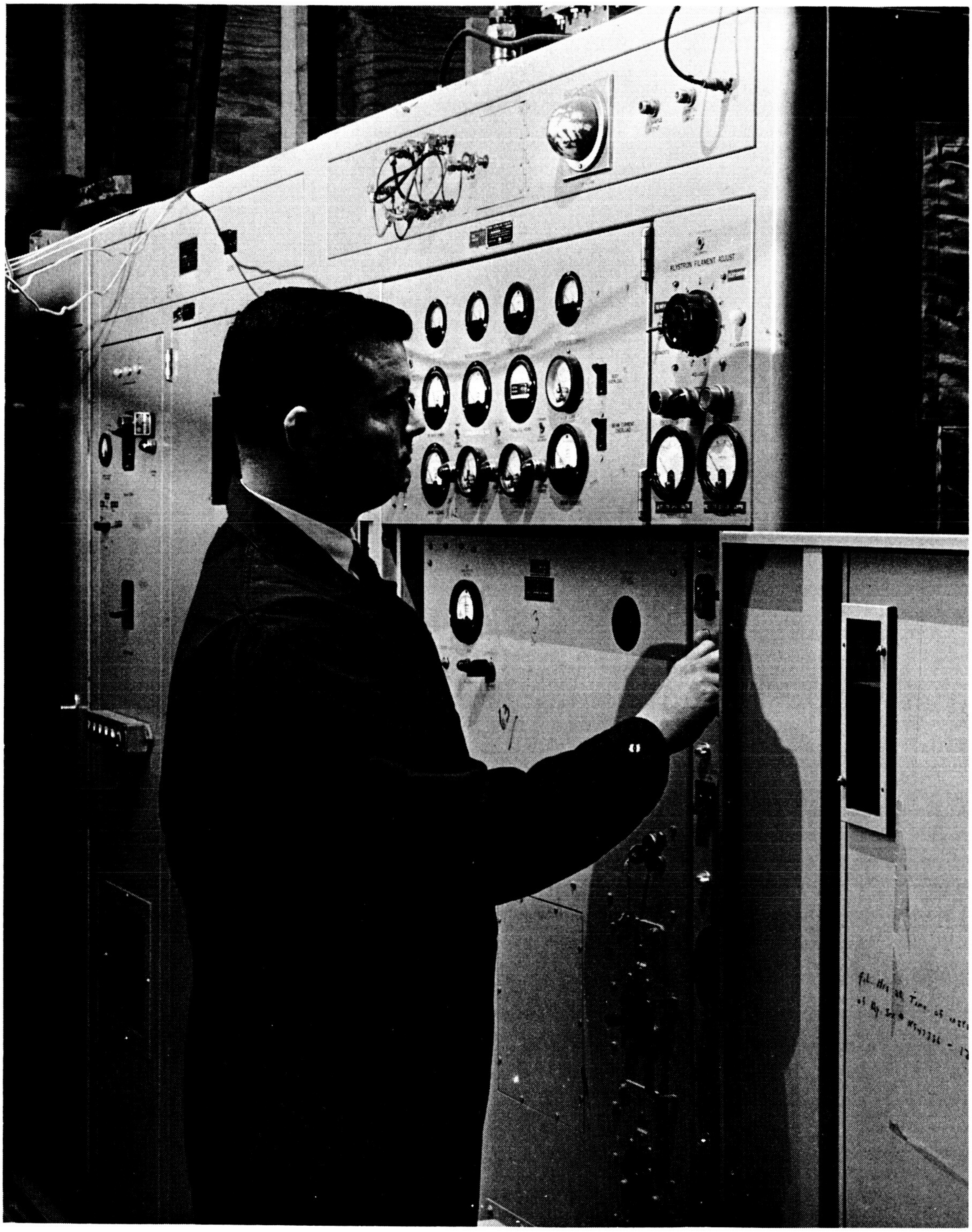

Fig. 11. 10 KW CW transmitter.

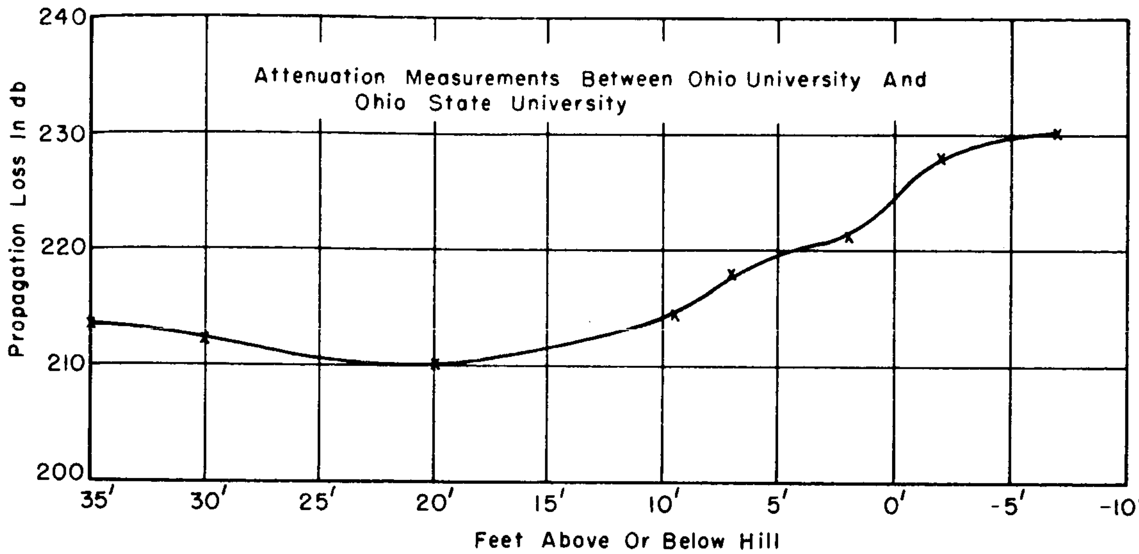

Fig. 12. Propagation loss between transmitter and receiver.

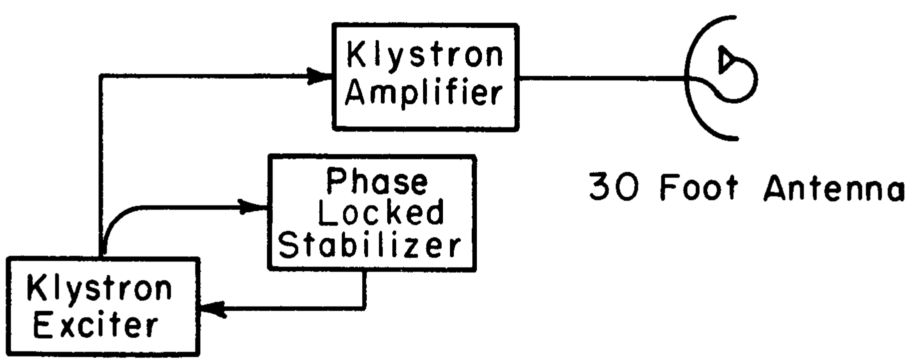

Fig. 13. Phase-locked frequency control.

V. CONCLUSIONS AND RECOMMENDATIONS

From the brief review above, it may be seen that work in several new and significant areas has been started during the year. In presenting our conclusions it will be convenient to suggest at the same time the most useful direction for future work.

A. Theoretical Studies

The polarization transforming properties of rough surfaces have been studied in some detail. From the general theory a number of useful relations have been derived which will permit (i) the interpretation of lunar radar experiments with mixtures of incident polarization states (includes the standard radar experiment using linear polarization relative to the earth based antenna system); (ii) permit complete specification of the scattering parameters of any surface from a few standard polarization measurements. A start has been made on the study of the relation between surface structure, and the results of "adjacent frequency" scattering experiments. Since such measurements offer considerable promise for determining surface structure, if properly interpreted, it is recommended that these studies be continued to a point where a clear understanding of at least the "two-frequency" radar experiment has been obtained.

B. Surface Scattering Studies

A number of moon-like surfaces have been constructed, and their bistatic scattering cross-sections measured on a recently completed bi-static range. It is recommended that these measurements be continued, and that a wider variety of surfaces, particularly those with an easily calculated cross-section, be measured. In addition, complete polarization properties should be measured, according to the systematic procedures developed under the theoretical studies. With sufficient such data, it may then be possible to clarify the effects of dielectric constant, surface structure and statistics, packing density, etc. on the scattering cross-section, and thus also on the apparent (radiometer) temperature of the surface.

C. Lunar Radar Experiments

Major effort during the year, both in manpower and equipment, has been devoted to completing an S-band lunar radar system, using the already existing Ohio State University "Saucer Field" Array as the receiving system, and a 10 KW transmitter at Athens, Ohio as the sending system. The receiver and transmitter are both functioning, and transmission tests are expected to begin shortly. It is recommended that work on this radar system be continued. In particular, the pure CW measurements, which will provide an approach to the lunar scattering diagram via the doppler spectrum, should be completed. Later, it is expected that two frequency operation, or some other modulation system, can be introduced, in order to investigate the roughness structure for a variety of roughness/wavelength ratios.

REFERENCES

1. Annual Summary Report, Report 1388-7, 1 November 1962, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Grant Number NsG-213-61, National Aeronautics and Space Administration, Washington, D.C.

2. Semi-Annual Report, Report 1388-10, 1 June 1963, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Grant Number NsG-213-61, National Aeronautics and Space Administration, Washington, D.C.

3. Barrick, D.E., Report in process.

4. Compton, R.T., Jr., "The Solution of an Integral Equation for the Lunar Scattering Function," Report 1388-8, 1 April 1963, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Grant Number NsG-213-61, National Aeronautics and Space Administration, Washington, D.C.

5. Kirschbaum, H.S. and Chen, S.N.C., "A Method of Producing Broadband Circular Polarization Employing an Anisotropic Dielectric," Trans. of IRE, PGMTT, p. 199, 1957.

6. Peake, W.H., and Taylor, R.C., "Radar Back-Scattering Measurements from Moon-Like Surfaces," Report 1388-9, 1 May 1963, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Grant Number NsG-213-61, National Aeronautics and Space Administration, Washington, D.C.

THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION

PROJECT SUMMARY STATEMENT

SPONSOR National Aeronautics & Space Administration
Washington 25, D. C.

DATE Oct. 31, 1963

SUPERVISOR C. A. LEVIS

CONTRACT NO.

PROJECT NUMBER 1388

COST CLASSIFICATION	CURRENT MONTH BUDGET	CURRENT MONTH EXPENDITURES	CURRENT BUDGET PERIOD 11/1/62 TO 10/31/63 BUDGET	EXPENDITURES TO DATE	OUTSTANDING COMMITMENTS	UNENCUMBERED BALANCE
SALARIES AND WAGES		2,827.12	63,134.00	38,478.42	.00	24,655.58
MATERIALS, EQUIPMENT & SERVICES		5,967.67	10,966.00	16,134.57	9,128.58	14,297.15 CR
TRAVEL EXPENSE		20.02	900.00	411.55	.00	488.45
OTHER DIRECT CHARGES						
OVERHEAD OR OPERATING CHARGES		1,173.25	20,000.00	15,235.39	.00	4,764.61
Equipment		13,917.38	5,000.00	16,378.35	.00	11,378.35 CR
TOTALS CURRENT BUDGET		23,905.44	100,000.00	86,638.28	9,128.58	4,233.14
TOTALS OF PRIOR BUDGET PERIOD 11/1/61 TO 10/31/62		.00	50,000.00	48,339.31	.00	1,660.69
CONTRACT TOTALS		23,905.44	150,000.00	134,977.59	9,128.58	5,893.83

FORM 100

IMPORTANT NOTE: No deduction has been made from the Unencumbered Balance for future overhead charges.